Interaction between Tachyon and Hessence (or Hantom) Dark Energies

Surajit Chattopadhyay[1*] **and Ujjal Debnath**[2†]

[1]*Department of Computer Application, Pailan College of Management and Technology, Kolkata-104, India.*
[2]*Department of Mathematics, Bengal engineering and Science University, Howrah-103, India.*
(Dated: October 8, 2010)

In this paper, we have considered that the universe is filled with tachyon, hessence (or hantom) dark energies. Subsequently we have investigated the interactions between tachyon and hessence (hantom) dark energies and calculated the potentials considering the power law form of the scale factor. It has been revealed that the tachyonic potential always decreases and hessence (or hantom) potential increases with corresponding fields. Furthermore, we have considered a correspondence between the hessence (or hantom) dark energy density and new variable modified Chaplygin gas energy density. From this, we have found the expressions of the arbitrary positive constants B_0 and C of new variable modified Chaplygin gas.

PACS numbers:

I. INTRODUCTION

Accelerated expansion of the universe is well documented in literature [1]. This accelerated expansion is consistent with the luminosity distance as a function of redshift of distant Supernova, the structure formation and the cosmic microwave background. A lot of recent observations have suggested that the universe mainly consists of dark energy (73%), dark matter (23%), baryon matter (4%) and negligible radiation. To accelerate the expansion, the equation-of-state parameter $\omega = \frac{p}{\rho}$ of the dark energy must satisfy $\omega < -\frac{1}{3}$, where p and ρ are its pressure and energy density. The simplest candidate for its expansion is cosmological constant Λ, for which the equation of state is $\omega = -1$. However, there are several other evidences showing that the dark energy might evolve from $\omega > -1$ in the past to $\omega < -1$ today. The critical state $\omega = -1$ is crossed in the intermediate redshift. Another possibility is quintessence [2] which gives $-1 \le \omega \le 0$. However, the k-essence models [3] and the phantom models [4] can get the state $\omega < -1$. As the behaviour of ω crossing -1 can not be realized, more complex models have suggested by several authors. The quintom model, a hybrid of quintessence and phantom has been studied in significant number of literature [5]. We consider the action

$$S = \int d^4x \sqrt{-g} \left(-\frac{\mathcal{R}}{16\pi G} + \mathcal{L}_{DE} + \mathcal{L}_m \right) \tag{1}$$

where, g is the determinant of the metric $g_{\mu\nu}$, $\mathcal{R}$ is the Ricci scalar, L_{DE} and L_m are the Lagrangian densities of dark energy and dark matter respectively. The quintom dark energy has the Lagrangian density

$$\mathcal{L}_{DE} = \frac{1}{2}[(\partial_\mu \phi_1)^2 + (\partial_\mu \phi_2)^2] - V(\phi_1, \phi_2) \tag{2}$$

where ϕ_1 and ϕ_2 are real scalar fields and play the roles of quintessence and phantom respectively. In a spatially flat FRW universe, under the assumption that ϕ_1 and ϕ_2 are homogeneous, the effective equation of state is given by

$$\omega = \frac{\dot{\phi_1}^2 - \dot{\phi_2}^2 - 2V(\phi_1, \phi_2)}{\dot{\phi_1}^2 - \dot{\phi_2}^2 + 2V(\phi_1, \phi_2)} \tag{3}$$

---

[*] surajit_2008@yahoo.co.in
[†] ujjaldebnath@yaghoo.com

It is obvious that for $\dot{\phi_1}^2 > \dot{\phi_2}^2$ we get $\omega > -1$ (i.e., quintessence model) and for $\dot{\phi_1}^2 < \dot{\phi_2}^2$ we get $\omega < -1$ (i.e., phantom model).

On the other hand there have been difficulties in obtaining accelerated expansion from fundamental theories such as M/String theory [6]. Much has been written and emphasized about the role of the fundamental dilation field in the context of string cosmology. But, not much emphasized is tachyon component [7]. It has been recently shown by Sen [8, 9] that the decay of an unstable D-brane produces pressure-less gas with finite energy density that resembles classical dust. The cosmological effects of the tachyon rolling down to its ground state have been discussed by Gibbons [10]. Rolling tachyon matter associated with unstable D-branes has an interesting equation of state which smoothly interpolates between -1 and 0. As the Tachyon field rolls down the hill, the universe experiences accelerated expansion and at a particular epoch the scale factor passes through the point of inflection marking the end of inflation [6]. The tachyonic matter might provide an explanation for inflation at the early epochs and could contribute to some new form of cosmological dark matter at late times [11]. Inflation under tachyonic field has also been discussed in ref. [7, 12, 13]. Sami et al [14] have discussed the cosmological prospects of rolling tachyon with exponential potential.

The action for the homogeneous tachyon condensate of string theory in a gravitational background is given by,

$$S = \int \sqrt{-g} \, d^4x \left[\frac{\mathcal{R}}{16\pi G} + \mathcal{L} \right] \tag{4}$$

where $\mathcal{L}$ is the Lagrangian density given by,

$$\mathcal{L} = -V(\phi)\sqrt{1 + g^{\mu\nu} \, \partial_\mu\phi\partial_\nu\phi} \tag{5}$$

where ϕ is the tachyonic field, $V(\phi)$ is the tachyonic field potential and $\mathcal{R}$ is the Ricci Scalar.

The Chaplygin gas is characterized by an exotic equation of state $p = -\frac{B}{\rho}$, where B is a positive constant. Role of Chaplygin gas in the accelerated universe has been studied by several authors [15]. The above mentioned equation of state has been modified to $p = -\frac{B}{\rho^\alpha}$ with $0 \le \alpha \le 1$. This is called generalized Chaplygin gas [16]. This equation has been further modified to $p = A\rho - \frac{B}{\rho^\alpha}$ with $0 \le \alpha \le 1$. This is called modified Chaplygin gas [17]. This equation of state shows radiation era at one extreme and ΛCDM model at the other extreme. Debnath [18] introduced a variable modified Chaplygin gas with B as a function of the scale factor a and the equation of state is $p = A\rho - \frac{B(a)}{\rho^\alpha}$.

Although the two dark components are usually studied under the assumption that there is no interaction between them, one can not exclude such a possibility. In fact, researches show that a presumed interaction may help alleviate the coincidence problem [19]. Some models that allow interaction between the scalar field and the matter field have been proposed as a solution to the cosmic coincidence problem [20]. Models based on dark energy interacting with dark matter have been widely investigated by several authors. These models yield stable scaling solution of the FRW equations at late times of the evolving universe. Interacting Chaplygin gas allows the universe to cross the phantom divide, which is not possible by the pure Chaplygin gas [20]. There is a report that this interaction is physically observed in the Abell cluster A586, which in fact supports the GCG cosmological model and apparently rules out the ΛCDM model [21]. Herrera et al (2004) [22] considered interacting mixture of cold dark matter and a tachyonic field. In this study they assumed that both components -the tachyon field and the cold dark matter- do not conserve separately but that they interact through a term Q and found exact solutions leading to power law accelerated expansion for a homogeneous, isotropic and spatially flat universe, dominated by an interacting mixture of cold dark matter and a tachyonic field. Setare et al (2009) [23] considered an interaction between the tachyonic field and the barotropic fluid and obtained the pressure and energy densities by choosing the interaction term Q as proportional to the density of the barotropic fluid and the Hubble parameter. Similar choice of interaction term Q was adopted in Amendola et al (2007) [24], who considered dark matter-dark energy interaction and discussed its consequences on cosmological parameters derived from SNIa data. In a recent paper, Sheykhi (2010) [25] demonstrated that the interacting agegraphic evolution of the universe can be described completely by a single tachyon scalar field and thus reconstructed the potential as well as the dynamics of the tachyon field according to the evolutionary behavior of interacting agegraphic dark energy. Wei and Cai (2005) [26] considered an interaction between hessence and and background perfect fluid through an interaction term described earlier. In the context of the literature surveyed, we decided to consider a two-component model, where instead of dark energy and

dark matter components, we decided to consider two candidates of dark energy (tachyon and hessence) in an interacting situation. We reconstructed the scalar fields and potentials of both of the candidates under interaction. Furthermore, we studied a correspondence hessence and new variable modified Chaplygin gas.

The organization of the paper is as follows: Section II describes the Lagrangian form of hessence and hantom dark energies. In section III, we have investigated the interaction between tachyon and hessence (or hantom) dark energies. In section IV, we have shown hessence (or hantom) as new variable modified Chaplygin gas and found the expressions of the arbitrary positive constants of new variable modified Chaplygin gas. Finally, the paper ends with a short discussion in section V.

II.   HESSENCE AND HANTOM DARK ENERGIES

The non-canonical complex scalar field has been given the name "hessence" [27]. The Lagrangian density of hessence is given by

$$\mathcal{L}_{he} = \frac{1}{4}[(\partial_\mu\phi_1)^2 + (\partial_\mu\phi_2)^2] - V(\phi_1^2 - \phi_2^2) \tag{6}$$

Now $\phi_1^2 - \phi_2^2$ = constant is a hyperbola on the ϕ_1 versus ϕ_2 plane and using the relations between angular functions and hyperbolic functions we can define the transformations given by

$$\phi_1 \longrightarrow \phi_1 cosh(i\alpha) - \phi_2 sinh(i\alpha) \quad , \qquad \phi_2 \longrightarrow -\phi_1 sinh(i\alpha) + \phi_2 cosh(i\alpha) \tag{7}$$

Now consider two new variables ϕ and θ to describe the hessence as

$$\phi_1 = \phi cosh\theta \quad , \qquad \phi_2 = \phi sinh\theta \tag{8}$$

which are defined by

$$\phi^2 = \phi_1^2 - \phi_2^2 \quad , \qquad coth\theta = \frac{\phi_1}{\phi_2} \tag{9}$$

then the transformation equation (7) is equivalent to

$$\phi \longrightarrow \phi \qquad and \qquad \theta \longrightarrow \theta - i\alpha \tag{10}$$

which means an internal imaginary motion. Thus formulation of (ϕ, θ) is to describe the non-canonical complex scalar field. Now we can write the Lagrangian density of the hessence in the form:

$$\mathcal{L}_{he} = \frac{1}{2}[(\partial_\mu\phi)^2 - \phi^2(\partial_\mu\theta)^2] - V(\phi) \tag{11}$$

The Lagrangian density of hantom is given by

$$\mathcal{L}_{he} = \frac{1}{4}[(\partial_\mu\phi_1)^2 + (\partial_\mu\phi_2)^2] - V(\phi_2^2 - \phi_1^2) \tag{12}$$

Again consider two variables ϕ and θ to describe the hantom as

$$\phi_1 = \phi sinh\theta \quad , \qquad \phi_2 = \phi cosh\theta \tag{13}$$

which are defined by

$$\phi^2 = \phi_2^2 - \phi_1^2 \quad , \qquad coth\theta = \frac{\phi_2}{\phi_1} \tag{14}$$

Now we can write the Lagrangian density of the hantom in the form

$$\mathcal{L}_{he} = -\frac{1}{2}[(\partial_\mu\phi)^2 - \phi^2(\partial_\mu\theta)^2] - V(\phi) \tag{15}$$

III.   INTERACTION BETWEEN TACHYON AND HESSENCE (OR HANTOM) DARK ENERGIES

Considering the spatially flat FRW universe with metric

$$ds^2 = dt^2 - a^2(t)\left[dr^2 + r^2(d\theta^2 + \sin^2\theta d\phi^2)\right] \tag{16}$$

where $a(t)$ is the expansion scalar or the scale factor. From (11) and (15) we have the pressure and energy densities of hessence (or hantom) as

$$p_h = \frac{\epsilon}{2}(\dot{\phi}^2 - \phi^2\dot{\theta}^2) - V(\phi) \tag{17}$$

and

$$\rho_h = \frac{\epsilon}{2}(\dot{\phi}^2 - \phi^2\dot{\theta}^2) + V(\phi) \tag{18}$$

where $\dot{\theta} = \frac{Q}{a^3\phi^2}$, Q is the total conserved energy = constant. The symbol ϵ is used to represent hessence ($\epsilon = 1$) and hantom ($\epsilon = -1$) using one equation for pressure and equation for density. To consider the interaction between the hessence (or hantom) and tachyon, we denote $V(\phi)$ of tachyon as V_1 and that of hessence (or hantom) as V_2. The fields of tachyon and hessence (or hantom) are denoted as ϕ_1 and ϕ_2 respectively. To denote pressure and energy densities of tachyon we use 1 in subscript and to denote hessence (or hantom) we use 2 in subscript.

Thus the pressure and energy densities of tachyonic field are given by

$$p_1 = -V_1(\phi_1)\sqrt{1 - \dot{\phi}_1^2} \tag{19}$$

and

$$\rho_1 = \frac{V_1(\phi_1)}{\sqrt{1 - \dot{\phi}_1^2}} \tag{20}$$

The pressure and energy densities of hessence (or hantom) are

$$p_2 = \epsilon\left(\frac{1}{2}\dot{\phi}_2^2 - \frac{Q^2}{2a^6\phi_2^2}\right) - V_2(\phi_2) \tag{21}$$

and

$$\rho_2 = \epsilon\left(\frac{1}{2}\dot{\phi}_2^2 - \frac{Q^2}{2a^6\phi_2^2}\right) + V_2(\phi_2) \tag{22}$$

Introducing the interaction parameter δ, the equations for continuity becomes

$$\dot{\rho}_1 + 3H(\rho_1 + p_1) = 3H\delta\rho_2 \tag{23}$$

and

$$\dot{\rho}_2 + 3H(\rho_2 + p_2) = -3H\delta\rho_2 \tag{24}$$

From the equation (24) we get

$$\epsilon\left[\ddot{\phi}_2 + 3H\left(1 + \frac{\delta}{2}\right)\dot{\phi}_2\right] + \left[\frac{\dot{V}_2}{\dot{\phi}_2} + 3H\delta\frac{V_2}{\dot{\phi}_2} + \epsilon\left(\frac{Q^2}{\phi_2^3 a^6} - \frac{3H\delta Q^2}{2a^6\phi_2^2\dot{\phi}_2}\right)\right] = 0 \tag{25}$$
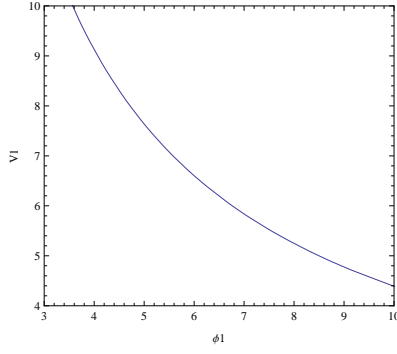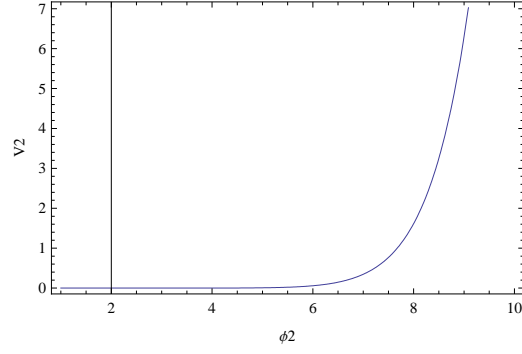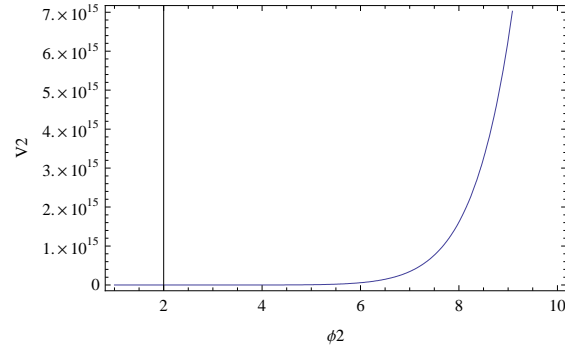
Fig.1

Fig.2

Fig.3

Figs. 1, 2 and 3 represent the variations of potentials against tachyon, hessence ($\epsilon = +1$) and hantom ($\epsilon = -1$) fields respectively.

Let us assume,

$$\frac{dV_3}{d\phi_2} = \frac{\dot{V}_2}{\dot{\phi}_2} + 3H\delta\frac{V_2}{\dot{\phi}_2} + \epsilon\left(\frac{Q^2}{\phi_2^3 a^6} - \frac{3H\delta Q^2}{2a^6\phi_2^2\dot{\phi}_2}\right) \tag{26}$$

where, V_3 is a function of ϕ_2. Thus, from equations (25) and (26), we get

$$\epsilon\ddot{\phi}_2 + 3H\epsilon\left(1 + \frac{\delta}{2}\right)\dot{\phi}_2 + \frac{dV_3}{d\phi_2} = 0 \tag{27}$$

For simplicity, let us choose $V_3 = n\dot{\phi}_2{}^2$ and $a = a_0 t^m$, we get

$$\phi_2 = \frac{C_0}{1+\alpha}a_0^{\frac{1}{m}}t^{1+\alpha} \tag{28}$$

where a_0 and C_0 are positive constants, $\alpha = -\frac{3m\epsilon}{2}\left(\frac{2+\delta}{2n+1}\right)$ and for this α we get

$$V_3 = nC_0^2 a_0^{\frac{2\alpha}{m}}t^{2\alpha} \tag{29}$$

Therefore, from equations (26), (28) and (29), it can be obtained that the expression for hessence (or hantom) potential V_2 as

$$V_2 = C_1 \left(\frac{(1+\alpha)a_0^{-\frac{\alpha}{m}}\phi_2}{C_0} \right)^{-\frac{3m\delta}{1+\alpha}} + \frac{2\alpha C_0^2 a_0^{6+\frac{2\alpha}{m(1+\alpha)}}}{2\alpha + 3m\delta} \left(\frac{(1+\alpha)\phi_2}{C_0} \right)^{\frac{2\alpha}{1+\alpha}} +$$

$$\frac{4na_0^6 C_0^4 Q^2 \epsilon \left\{ 2(1+\alpha) - 3m\delta a_0^{-\frac{2\alpha}{m}} \right\}}{2(1+\alpha) - 3m(-2+\delta)} \left(\frac{(1+\alpha)\phi_2 a_0^{-\frac{\alpha}{m}}}{C_0} \right)^{-\frac{2(1+\alpha+3m)}{1+\alpha}} \tag{30}$$

where C_1 is arbitrary integration constant. Now from equation (23), we get

$$P = \frac{2 - 3\dot{\phi_1}^2}{\sqrt{1 - \dot{\phi_1}^2}} \tag{31}$$

where,

$$P = -\frac{6m(m-1)}{t^2} - 2C_1 t^{-3m\delta} + 2a_0^{\frac{2\alpha}{m}} t^{2\alpha} \left(C_0^2 - \frac{2\alpha C_0^2 a_0^6}{2\alpha + 3m\delta} \right) -$$

$$2(1+\alpha)^2 Q t^{-2(1+\alpha+3m)} \left[\frac{a_0^{-6-\frac{2\alpha}{m}}}{C_0^2} + \frac{4na_0^6 C_0^4 Q\epsilon \left\{ 2(1+\alpha) - 3m\delta a_0^{-\frac{2\alpha}{m}} \right\}}{2(1+\alpha) - 3m(-2+\delta)} \right] \tag{32}$$

Furthermore, it can be obtained that the expressions for tachyonic potential V_1 and tachyonic field ϕ_1 as

$$V_1 = C_1 t^{-3m\delta} + \frac{\alpha t^{2\alpha-1}}{2C_0^2 a_0^6(-1+2\alpha+3m\delta)} + \frac{2C_0^2 a_0^6(1+\alpha)^2 Q^2 t^{-2(1+\alpha+3m)}\{\epsilon(1+\alpha+3m) + \alpha(1+2n)\}}{2(1+\alpha) - 3m(-2+\delta)} \tag{33}$$

and

$$\phi_1 = \int \sqrt{\frac{2}{3} - \frac{P^2}{18} - \frac{P}{18}\sqrt{12+P^2}} \; dt \tag{34}$$

From above expressions, we see that expression of ϕ_1 is very complicated, so V_1 can not be expressed in terms of ϕ_1 explicitly. So some numerical investigations are needed to see the nature of tachyonic potential. From figure 1, it is discerned that the tachyonic potential is decreasing with the field and figure 2, 3 show that the hessence and hantom potentials are increasing with the corresponding fields for $m = 1, n = 2, a_0 = 1$.

IV. HESSENCE (OR HANTOM) AS NEW VARIABLE MODIFIED CHAPLYGIN GAS

In the present section, we consider hessence (or hantom) as gas as new variable modified Chaplygin gas. The endeavor is to establish a correspondence between the hessence (or hantom) and the variable modified Chaplygin gas model. Assuming $B(a) = B_0 a^{-n}$ in the equation of state of the variable modified Chaplygin gas with $B_0 > 0$ and n as positive constant we get the solution for ρ as

$$\rho_\Lambda = \left[\frac{3(1+\alpha)B_0}{3(1+\alpha)(1+A) - n} \frac{1}{a^n} + \frac{C}{a^{3(1+A)(1+\alpha)}} \right]^{\frac{1}{1+\alpha}} \tag{35}$$

Taking derivatives of both sides with respect to cosmic time we get

$$\dot{\rho}_\Lambda = 3H \left[Ca^{-(1+A)(1+\alpha)} + \frac{3(1+\alpha)a^{-n}B_0}{3(1+A)(1+\alpha) - n} \right]^{-\frac{\alpha}{1+\alpha}} \left[-(1+A)Ca^{-3(1+A)(1+\alpha)} - \frac{na^{-n}B_0}{3(1+A)(1+\alpha) - n} \right] \tag{36}$$

Using the equation of density (22) for hessence (or hantom) (write ρ_Λ instead of ρ_2) we get

$$\dot{\rho}_\Lambda = -32^\alpha H \left[(1+A)Ca^{-3(1+A)(1+\alpha)} + \frac{na^{-n}B_0}{3(1+A)(1+\alpha)-n} \right] \left[-2V_2 + \epsilon \left(-\frac{Q^2}{a^6\phi_2^2} + \dot{\phi}_2^2 \right) \right]^{-\alpha} \tag{37}$$

and

$$p_\Lambda = 2^\alpha a^{-n} \left[ACa^{n-3(1+A)(1+\alpha)} + \frac{(n-3(1+\alpha)B_0)}{3(1+A)(1+\alpha)-n} \right] \left[-2V_2 + \epsilon \left(-\frac{Q}{a^6\phi_2^2} + \dot{\phi}_2^{\,2} \right) \right]^{-\alpha} \tag{38}$$

From the equations of continuity the effective equation of state is

$$\omega_\Lambda^{eff} = A - \frac{B_0 a^{-n}}{\rho_\Lambda^{1+\alpha}} + \frac{\delta}{3H} \tag{39}$$

Following reference [28] in the above equation we use $\delta = \frac{3b^2 H(1+\Omega_k)}{\Omega_\Lambda}$ to get

$$\omega_\Lambda^{eff} = A - \frac{B_0 a^{-n}}{(3M_p^2 H^2 \Omega_\Lambda)^{1+\alpha}} + \frac{b^2(1+\Omega_k)}{\Omega_\Lambda} \tag{40}$$

where,

$$\Omega_\Lambda = \frac{\rho_\Lambda}{3M_p^2 H^2} \ , \ \Omega_k = \frac{k}{a^2 H^2} \tag{41}$$

In non-flat universe, our choice for hessence (or hantom) energy density is

$$\rho_\Lambda = -V_2 + \frac{\epsilon}{2} \left(-\frac{Q^2}{a^6\phi_2^2} + \dot{\phi}_2^2 \right) \tag{42}$$

we get (using the continuity equations (21) and (22)) the values of arbitrary constants B_0 and C as

$$B_0 = \frac{a^n \{3(1+A)(1+\alpha)-n\}}{3(1+\alpha)} \left[\left\{ -V_2 + \frac{\epsilon}{2} \left(-\frac{Q^2}{a^6\phi_2^2} + \dot{\phi}_2^2 \right) \right\}^{1+\alpha} - \frac{C}{a^{3(1+\alpha)(1+A)}} \right] \tag{43}$$

$$C = \frac{3(1+\alpha)a^{3(1+A)(1+\alpha)}}{3(1+A)(1+\alpha)-n} \left[(3M_p^2 H^2 \Omega_\Lambda)^{1+\alpha} \left(-\frac{1}{3} - A - \frac{b^2(1+\Omega_k)}{\Omega_\Lambda} - \frac{2\sqrt{\Omega_\Lambda - c^2\Omega_k}}{3c} \right) \right.$$

$$\left. + \frac{\{3(1+A)(1+\alpha)-n\}}{3(1+\alpha)} \left\{ -V_2 + \frac{\epsilon}{2} \left(-\frac{Q^2}{a^6\phi_2^2} + \dot{\phi}_2^2 \right) \right\}^{1+\alpha} \right] \tag{44}$$

V. CONCLUSIONS

In this paper, we have considered that the universe is filled with tachyon, hessence (or hantom) dark energies. Subsequently we have investigated the interactions between tachyon and hessence (or hantom) dark energies and calculated the potentials considering the power law form of the scale factor. It has been revealed that the tachyonic potential V_1 always decreases with ϕ_1 and hessence (or hantom) potential V_2 increases with corresponding field ϕ_2. Furthermore, we have considered a correspondence between the hessence (or hantom) dark energy density and new variable modified Chaplygin gas energy density. From this, we

have found the expressions of the arbitrary positive constants B_0 and C of new variable modified Chaplygin gas.

References:

[1] N. A. Bachall, J. P. Ostriker, S. Perlmutter and P. J. Steinhardt, *Science* **284** 1481 (1999); S. J. Perlmutter et al, *Astrophys. J.* **517** 565 (1999); V. Sahni and A. A. Starobinsky, *Int. J. Mod. Phys. A* **9** 373 (2000); P. J. E. Peebles and B. Ratra, *Rev. Mod. Phys.* **75** 559 (2003); T. Padmanabhan, *Phys. Rept.* **380** 235 (2003); E. J. Copeland, M. Sami, S. Tsujikawa, *Int. J. Mod. Phys. D* **15** 1753 (2006).
[2] C. Wetterich, *Nucl. Phys. B* **302** 668 (1988).
[3] C. Armendariz-Picon, V.F. Mukhanov and P. J. Steinhardt, *Phys. Rev. D* **63** 103510 (2001).
[4] R. R. Caldwell, *Phys. Lett. B* **545** 23 (2002); S. Nojiri, S. D. Odintsov, *Phys. Rev. D* **72** 023003 (2005).
[5] B. Feng, X. L. Wang and X. M. Zhang, *Phys. Lett. B* , **607** 35 (2005); X. Zhang, *Commun. Theor. Phys.* **44** 762 (2005).
[6] M. Sami, *Mod. Phys. Lett. A* **18** 691 (2003).
[7] A. Feinstein, *Phys. Rev. D* **66** 063511 (2002).
[8] A. Sen, *JHEP* **0204** 048 (2002).
[9] A. Sen, *JHEP* **0207** 065 (2002).
[10] G. W. Gibbons, *Phys. Lett. B* **537** 1 (2002).
[11] M. Sami, P. Chingangbam and T. Qureshi, *Phys. Rev. D* **66** 043530 (2002).
[12] M. Fairbairn and M. H. G. Tytgat, *Phys. Lett. B* **546** 1 (2002).
[13] T. Padmanabhan, *Phys. Rev. D* **66** 021301 (2002).
[14] M. Sami, P. Chingangbam and T. Qureshi, *Pramana* **62** 765 (2004).
[15] A. Kamenshchik, U. Moschella and V. Pasquier, *Phys. Lett. B* **511** 265 (2001); V. Gorini, A. Kamenshchik, U. Moschella and V. Pasquier, *gr-qc/0403062*.
[16] V. Gorini, A. Kamenshchik and U. Moschella, *Phys. Rev. D* **67** 063509 (2003); U. Alam, V. Sahni , T. D. Saini and A.A. Starobinsky, *Mon. Not. Roy. Astron. Soc.* **344**, 1057 (2003); M. C. Bento, O. Bertolami and A. A. Sen, *Phys. Rev. D* 66 043507 (2002).
[17] H. B. Benaoum, *hep-th/0205140*; U. Debnath, A. Banerjee and S. Chakraborty, *Class. Quantum Grav.* **21** 5609 (2004).
[18] U. Debnath, *Astrophys. Space Sc.* **312** 295 (2007).
[19] X. Fu, H. Yu, P. Wu, *Phys. Rev. D* **78** 063001 (2008).
[20] F. P. Zen et al, *Eur. Phys J. C* **63** 477 (2009).
[21] M. Jamil and M. A. Rashid, *Eur. Phys J. C* **58** 111 (2008).
[22] R. Herrera, D. Pavn, W. Zimdahl, *General Relativity and Gravitation* **36** 2161 (2004).
[23] M. R. Setare, J. Sadeghi, A. R. Amani, *Phys. Lett. B* **673** 241 (2009).
[24] L. Amendola, G. C. Campos, R. Rosenfeld, *Phys. Rev. D* **75** 083506 (2007).
[25] A. Sheykhi, *Phys. Lett. B* **682** 329 (2010).
[26] H. Wei, R.-G. Cai, *Phys. Rev. D* **72** 123507 (2005).
[27] H. Wei, R.G. Cai and D.F. Zeng, *Class. Quantum Grav.* **22** 3189 (2005).
[28] M. R. Setare, *Europhys. J. C* **52** 689 (2007).